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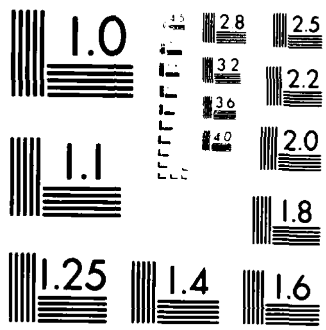

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COOPER RIVER REDIVERSION PROJECT

LAKE MOULTRIE AND SANTEE RIVER
SOUTH CAROLINA

THE EFFECT OF THE COOPER RIVER REDIVERSION CANAL ON THE GROUND-WATER REGIMEN OF THE ST. STEPHEN AREA, SOUTH CAROLINA

Prepared by

U. S. GEOLOGICAL SURVEY, WATER RESOURCES DIVISION
COLUMBIA, SOUTH CAROLINA

U.S. ARMY ENGINEER DISTRICT, CHARLESTON
CORPS OF ENGINEERS
Charleston, South Carolina
OCTOBER 1975

COPY NO.

SAHGE-F   9 January 1976

SUBJECT: Groundwater Report by U.S.G.S., Cooper River Rediversion Project

Division Engineer, South Atlantic
ATTN: SADEN-GK

1. Transmitted for review is the project Groundwater Report entitled, "The Effect of the Cooper River Rediversion Canal on the Groundwater Regimen of the St. Stephen Area, South Carolina". The report was prepared for the Corps by the Water Resources Division of the U. S. Geological Survey in Columbia, South Carolina.

2. A system of observation wells was installed at the project site during the groundwater study. It is presently planned to have U.S.G.S. collect water level data monthly from the well system for annual reporting. The annual reports, including the Survey's evaluation of significant project groundwater impacts shown by the well data, will be submitted annually as supplements to the subject report.

3. Work is presently underway on the well inventory that is scheduled for completion during this fiscal year (FY 76). Inventory data is being collected by the Corps under the direction of the Survey and the data will be logged on standard Survey data forms for storage in a computer information retrieval system. Well information pertinent to the project will be summarized and submitted as a supplement to the subject report.

4. Mr. Phil Johnson (U.S.G.S.) has requested that the subject report distribution be limited to in-house Corps review. Release of the report outside the Corps will require an administrative "open file" action by U.S.G.S. All outside requests for report copies should be referred to Mr. Johnson (FTS 677-5966).

1 Incl (5 cys)
as

HARRY S. WILSON, JR.
Colonel, Corps of Engineers
District Engineer

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

THE EFFECT OF THE COOPER RIVER REDIVERSION CANAL ON THE GROUND-WATER REGIMEN OF THE ST. STEPHENS AREA, SOUTH CAROLINA

By

Charles A. Spiers
U.S. Geological Survey

Prepared by the
U.S. GEOLOGICAL SURVEY
in cooperation with
THE U.S. ARMY CORPS OF ENGINEERS, CHARLESTON DISTRICT

Columbia, South Carolina
1975

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ABSTRACT

Heavy siltation of Charleston Harbor has caused the US Army Corps of Engineers to consider plans to divert the major flow of fresh water through a new canal to be constructed from the Lake Marion-Lake Moultrie-Cooper River complex to the Santee River. The US Geological Survey was asked to study the effect such a canal would have on the ground-water regimen of the area.

The drilling phase of the study consisted of 33 core holes located along and at right angles to the canal right-of-way. The purposes of the core holes were to delineate the subsurface geology and to locate possible sites for the observation well network. As a result, 20 observation wells were drilled in order to monitor water levels before, during, and after construction of the canal and power house.

As a result of the drilling program three aquifers in the study area were delineated: aquifer 1, a shallow (40-60 feet) sand which supplies limited amounts of water to wells; aquifer 2, a confined limestone (90-120 feet) which is the most widely used aquifer in the vicinity of the canal right-of-way; and aquifer 3, a sand and gravel remnant of a buried stream channel found in the flood plain.

An aquifer test was conducted at the power-house site. Aquifer 1 and 2 were pumped separately. The transmissivity of aquifer 1 was 870 ft^2/day (feet squared per day) (6,500 gal/day/ft) (gallons per day per foot) and the storage coefficient was 1×10^{-1}. The transmissivity of aquifer 2 was 455 ft^2/day (3,400 gal/day/ft) and its storage coefficient was 1×10^{-4}.

During construction of the power house foundation, heavy pumping of aquifers 1 and 2 will occur. Drawdowns of 80 feet or more will need to be maintained within the excavation.

It appears that excessive drawdowns arealy would not occur as a result of pumping aquifer 1. However, the assumed storage coefficient of .1 was used to derive "u" in the Theis equation. The drawdowns predicted from transmissivity and storage figures only give an estimate as to the actual drawdowns that would take place in the aquifer during pumping at the power house site.

Maximum drawdowns (aquifer 2) were computed without the recharge or leakance effect and minimum drawdowns were computed on the basis of "leakage". Considering only the effect of line-source recharge, the drawdowns would occur between the maximum and minimum computed values. Data shows that there would be very little drawdown arealy in aquifer 2 if the "leakage" assumptions are correct and a large amount of drawdown arealy if no recharge or leakage occurs.

The intake canal may recharge aquifers 1 and 2 as a result of head differences between the canal and the aquifers. Some recharge to the aquifers could occur at maximum stage in the tailrace canal. However, less head in the tailrace canal would cause a decrease in the recharge effect and stabilization of water levels between the aquifers and canal.

INTRODUCTION

Heavy siltation of Charleston Harbor has caused the US Corps of Engineers to consider several plans to divert the major flow of fresh water from the Lake Marion-Lake Moultrie-Cooper River complex. One of the plans is to redivert the water through a canal to be dug north of St. Stephen to the Santee River (fig. 1).

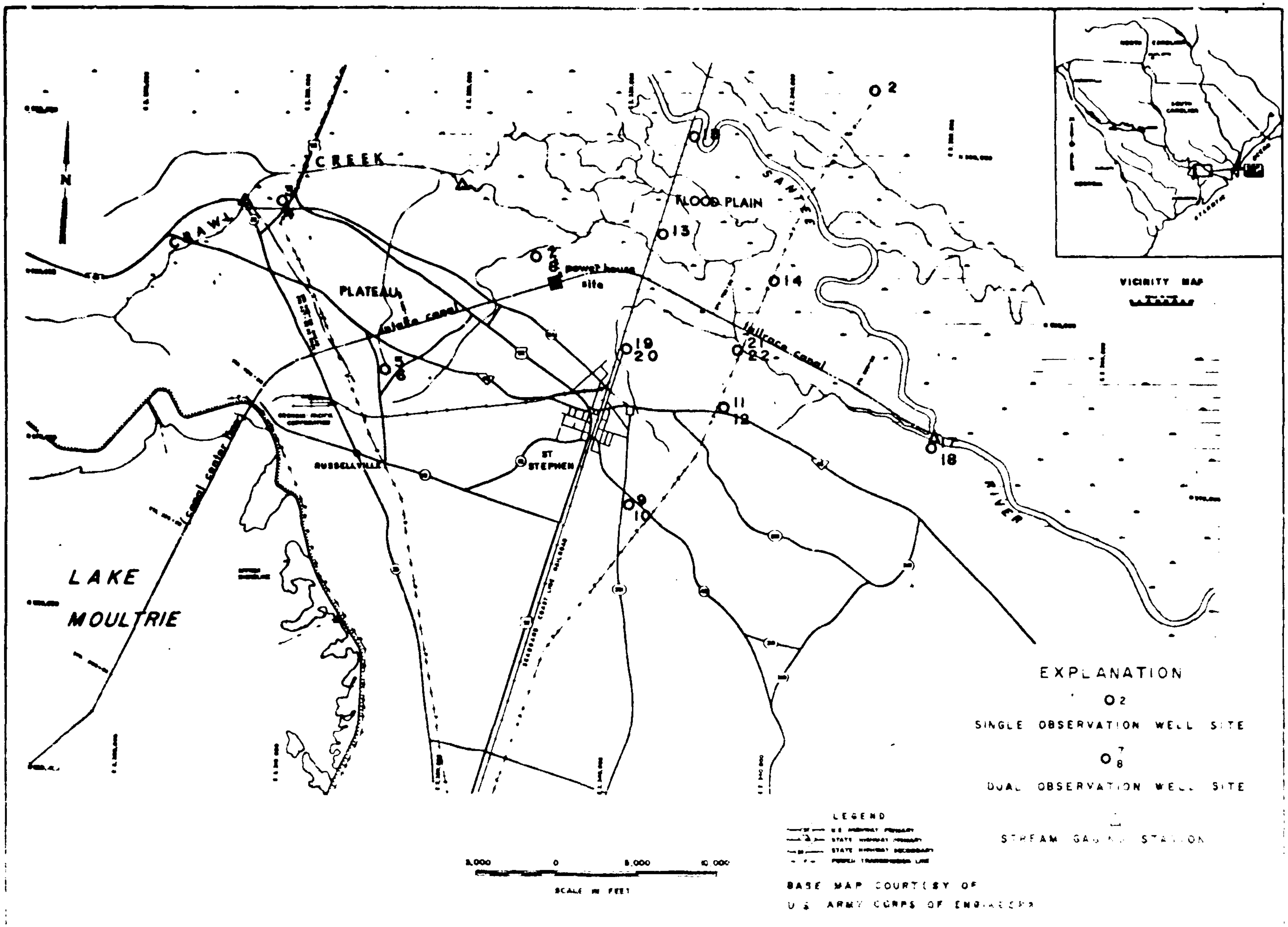
The canal will consist of three segments: (1) an intake canal from Lake Moultrie to the power house, with an excavation depth to 50 feet above mean sea level (msl); (2) a power house 200 x 300 feet, with an excavation depth to 42 feet below msl, and (3) a tailrace canal that [illegible] from the power house across the flood plain to the Santee River, with an excavation depth to 3.6 feet above msl. The Survey was asked to study the effects such a canal and power house would have on the ground-water regimen of the area. This report gives an analysis of data obtained.

The principal objectives of the ground-water study were:

1) To analyze and predict the effects that the canal will have upon the ground-water regimen of the adjacent areas; which includes the definition of the geohydrologic framework of the area, the canal's effect upon the underlying aquifers, ground water in surficial deposits, and loss or gain of water in the canal resulting from seepage; and

2) To establish a data collection network to document ground-water conditions at the project site after the project is completed.

Thirty-three core holes were drilled along and at right angles to the canal right-of-way. The purposes of the core holes were to



N
CRAWL
CREEK
PLATEAU
intake canal
power house site
FLOOD PLAIN
SANTEE
RIVER
tailrace canal
RUSSELLVILLE
ST STEPHEN
LAKE
MOULTRIE
canal center line
VICINITY MAP
EXPLANATION
SINGLE OBSERVATION WELL SITE
DUAL OBSERVATION WELL SITE
LEGEND
5,000
0
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SCALE IN FEET
BASE MAP COURTESY OF

delineate the subsurface geology and to locate p[illegible] observation-well network. Geophysical logs consisting [illegible] electric logs, and a few neutron logs were run in [illegible] test wells to aid in the interpretation of the st[illegible] area. To expand the area of investigation without [illegible] of test holes, gamma logs were run in 12 water wells [illegible] Williamsburg Counties in the vicinity of St. Step[illegible] with the core information were used in constructing [illegible] sections, thereby illustrating the stratigraphy and [illegible] work of the area. Surficial reconnaissance of the [illegible] established that Crawl Creek [illegible] enough into the [illegible] to possibly intercept the [illegible] aquifer. Therefore, [illegible] stations on Crawl Creek were installed. These stations will provide data on stream flow and help to define its relation to ground water discharge or recharge.

Twenty observation wells were drilled at selected locations (fig. 1) to monitor pre-construction and post-construction conditions and to evaluate possible changes in the hydrologic [illegible] a result of construction and filling of the canal. [illegible] well drilling program was begun in April 1973 and [illegible] In most cases, two wells were drilled at each site [illegible] changes in two separate aquifers. All observation [illegible] with 6-inch plastic pipe cemented in place from t[illegible] that was being monitored to ground level (table 1[illegible] casing was placed around the plastic pipe, above ground, to protect the well. The steel casing was also cemented into place. Short (2 hours) pumping tests were run on selected wells after completion. A submersible pump was set below the projected pumping level of the well and drawdown and recovery tests were made. Water samples obtained during these pumping tests were sent to the US Geological Survey's laboratory for analysis, in order to ascertain the chemical quality of the water from the two aquifers. Continuous graphic recorders with monthly or bi-monthly time scales were installed on all observation wells. Elevations to mean sea level datum were established by precision leveling to reference points al all observation wells by the Corps of Engineers and the Survey. Therefore, water levels are all adjusted to mean sea level.

GENERAL GEOLOGY AND STRATIGRAPHY

The sedimentary formations of the Coastal Plain range in age from Upper Cretaceous to Holocene. These formations consist of sand, clay gravel, marl, and limestone that have been deposited on a subsurface of granite, schist, and gneiss. The geologic formations in the St. Stephens area include, from youngest to oldest, deposits of Holocene, Pleistocene, middle Eocene (the Santee Limestone), lower Eocene and Paleocene (the Black Mingo Formation), Upper Cretaceous age (the Peedee Formation). The contacts between most of the geologic formations in the Coastal Plain and in the St. Stephens area are represented by unconformities. In general, the thickness of the sedimentary sequence increases from a

Table 1.--Location and construction data for observation wells.

Well	Latitude Longitude	Altitude: Surface of Ground	Altitude: Top of Casing	Depth of Well (ft)	Depth to Bottom of Casing (ft)	Well Screen, ft below ground: From	Well Screen, ft below ground: To	Uncased Section of well, ft below ground: From	Uncased Section of well, ft below ground: To
2	332655 0795200	44.54	47.74	60	40	-	-	40	60
3	332630 0795925	58.64	61.24	35	20	20	35	-	-
4	332630 0795925	58.57	61.17	130	102	-	-	102	130
5	332435 0795805	83.94	86.74	42	32	32	42	-	-
6	332435 0795805	84.06	87.76	173	140	-	-	140	[illegible]
7	332525 0795620	49.68	52.18	35	25	25	35	-	-
8	332525 0795620	49.59	53.39	113	73	-	-	73	113
9	332320 0795500	77.42	80.72	30	20	20	30	-	-
10	332320 0795500	77.31	80.71	140	120	-	-	120	140
11	332425 0795350	77.18	79.98	35	20	20	35	-	-
12	332425 0795350	77.05	80.45	143	125	-	-	125	140

Altitude inters msl datum.

Table 1.--Location and construction data for observation wells. (cont'd)

Well	Latitude Longitude	Altitude: Surface of Ground	Altitude: Top of Casing	Depth of Well (ft)	Depth to Bottom of Casing (ft)	Well Screen, ft below ground: From	Well Screen, ft below ground: To	Uncased Section of well, ft below ground: From	Uncased Section of well, ft below ground: To
13	332600 0795430	22.22	31.85	45	20	20	45	-	-
14	332535 0795320	22.34	31.64	35	20	20	35	-	-
15	332655 0795620	27.51	35.19	50	20	20	50	-	-
17	332350 0795110	31.06	34.36	25	20	20	25	-	-
18	332350 0795110	30.87	33.77	86	56	-	-	56	86
19	332455 0795455	71.91	74.61	32	21	21	31	-	-
20	332455 0795455	72.11	75.01	158	133	-	-	133	158
21	332450 0795335	20.71	30.91	28	13	13	28	-	-
22	332450 0795335	20.86	31.06	85	56	-	-	56	85

Altitudes are ft above mean sea level.

thin edge at the surface near the Fall line, 60 to 80 miles northwest of St. Stephens, to as much as 5,000 feet near the coast (Charleston area).

Holocene

Deposits of Holocene age consisting mostly of red and yellow sandy clay forms the surficial formation over most of the study area. The thickness of these deposits range from a few feet to several tens of feet.

Pleistocene

The Pleistocene deposits consist of a series of marine terraces that cover most of the Coastal Plain. They consist chiefly of gray sands and clays and occur from an altitude of about 270 feet to a few feet above sea level across the Coastal Plain.

In the St. Stephens area, the Pleistocene deposits underlie a mantle which consists of younger sediments in the area. Figure 2 describes a generalized geologic section of the St. Stephens area using a gamma log of test hole GS-13. As shown on the log, the maximum thickness of the Pleistocene deposits in the study area is approximately 50 feet. The Pleistocene deposits are divided into two distinct units: the sands and clays of the plateau area adjacent to the Santee River flood plain, and the coarse sands and gravel of the flood plain itself. During core drilling, an old stream channel, buried under silt deposited from inundation of the flood plain by the Santee River, was discovered. The buried remnant channel consists of medium-coarse glauconitic sands with some gravel beds.

G.S. Core hole 13

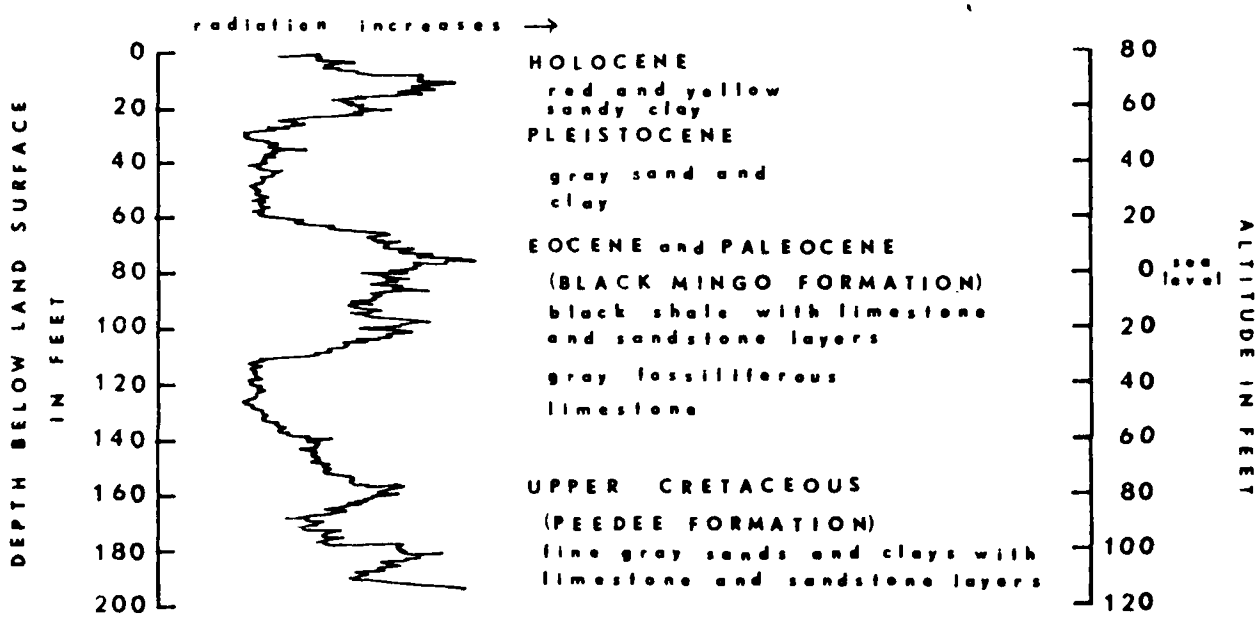


Figure 2.--Gamma log with lithologic interpretations showing generalized geologic section in the St. Stephens area.

Eocene

The Santee Limestone (middle Eocene), is a pure-white to creamy-yellow limestone that is partly glauconitic and outcrops in a broad belt from Berkeley County across to Barnwell County, South Carolina (fig. 3). The limestone is soft with partially indurated shell layers and lies unconformably on the Black Mingo Formation. In some places it outcrops as a greenish, calcareous, sandy deposit with some shell layering. The maximum thickness of the formation in the coastal plain does not exceed 300 feet.

The Santee Limestone occurs as a remnant in areas near St. Stephens, but it is not considered to be a significant geologic formation in the project area. Figure 2 does not show any appreciable base-line shift in the gamma log that would indicate this limestone inferring the Santee is Pleistocene. No shallow limestone was recorded in the lithologic log for core hole GS-13 or any of the other core holes drilled in the flood plain or plateau. However, some shallow limestone was encountered during core drilling in Lake Moultrie; this shallow limestone in the lake could possibly be Santee. Some calcareous sand, was noted in core holes near Lake Moultrie. These sands may be derived from Eocene deposits reworked in Pleistocene time or some local facies change from limestone to calcareous sand.

Eocene and Paleocene

The Black Mingo Formation of lower Eocene and Paleocene age is the basal formation of the Tertiary System in the St. Stephens area. The formation consists of two distinct units: (1) dark, brittle, shale with thin sandstone lenses and some shell layers; and (2) gray, fossiliferous limestone about 20-40 feet thick underlying the shale.

The Black Mingo Formation lies directly beneath the Pleistocene deposits both in the plateau and the flood plain areas near St. Stephens. It has been found to crop out at an altitude of about 30 feet, west of St. Stephens near Eadytown on the Santee River. It was described by Pooser (1969, p. 20) as, "a marl, bluish-green, with numerous small shell fragments of pelecypods and gastropods." The Black Mingo Formation lies at or near the surface in a broad belt that includes Georgetown, Williamsburg, Clarendon and Sumter Counties. Total thickness of the formation in the Coastal Plain probably does not exceed 100 feet. Numerous sink holes as well as outcrops in the stream beds delineate the Black Mingo Formation over a large area north and northwest of St. Stephens (fig. 3).

Cretaceous

The Peedee Formation is the youngest and uppermost Cretaceous unit in South Carolina. It consists of greenish-gray glauconitic sandy-marl, interbedded with thick, black clays. Outcrop areas are found in Florence, Horry, Georgetown and Williamsburg Counties. The slope of the Peedee Formation is in the southeast direction from the Fall Line. The formation thickness ranges from a thin edge near the Fall Line to 800 feet near Charleston.

The top of the Peedee Formation in the St. Stephens area is shown on a gamma log of core hole GS-13 (fig. 2). The altitude of the top of the formation is approximately minus 80 feet. A distinct base-line shift

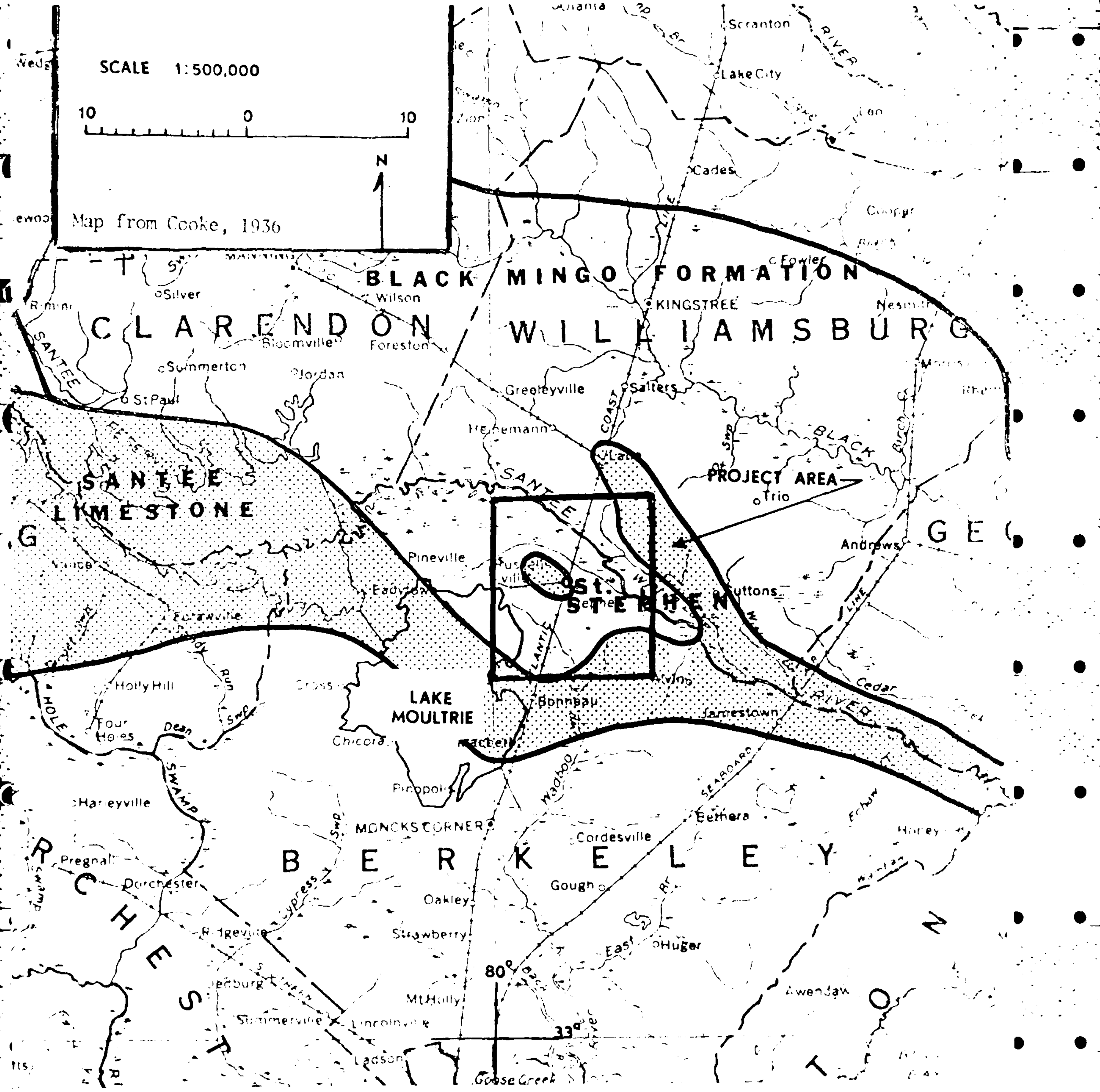


Figure 3.--Generalized occurrence of geologic formations.

on the gamma log indicates a change in lithology from limestone (Black Mingo Formation) to sandy clay and clays (Peedee Formation).

HYDROLOGY

Precipitation

Yearly rainfall in the area is fairly well distributed monthly and usually ranges between 40 to 50 inches per year. Over 60 inches of rain fell in 1964 and 1971, but during the entire year of 1954 the rainfall totaled only 24.14 inches. Rainfall recorded from October 1973 to September 1974 was 44.09 inches in the St. Stephens area.

Surface Water

Lower Santee Basin

The flow in the lower Santee River channel consists of water released from Wilson Dam on Lake Marion plus that contributed by the drainage area downstream from the dam, and ground-water discharge. The drainage area between the dam and river terminus of the proposed rediversion canal is about 200 square miles. A river swamp about 3 miles wide occupies the flood plain and cuts through the center of this drainage area, which is roughly 20 miles long and 10 miles wide. Much of the area is sandy, mixed with some light tan, gray, or red clay. Gravel beds are to be found beneath the surface in the swamp area, especially in the old buried river channel. There are some limestone outcropings and sinkholes, especially in the eastern half of the drainage area.

Streamflow

The flow released to the lower Santee River channel from Lake Marion at Wilson Dam is usually held to a minimum of 500 cfs (cubic feet per second). However, large flows are occasionally released due to excessive flooding upstream from Lake Marion. When this occurs, the lower Santee River channel overflows and inundates the adjoining 3-mile wide flood-plain swamp. The stage from these high flows is recorded almost immediately at the Survey's gaging station near Pineville, located about 2 miles downstream from Wilson Dam. About 33 river miles down stream from the dam or near the river terminus of the proposed rediversion canal. These flows show up a day or two later and the stage is recorded at the Survey's gaging station near St. Stephens. Mean daily discharge is usually higher at the St. Stephens gage than at the Pineville gage because generally the same rains which cause the releases through the dam also cause local flooding in the area below the dam. Some of the surface water in the swamp area probably infiltrates the sediments and is believed to recharge the underlying aquifers. High evapotranspiration rates and natural drainage back to the stream account for the rapidity with which the swampland "dries out" after being flooded.

During periods of base flow, when there is little or no direct run off from rainfall in the 200 square-mile drainage area, the increase in flow between the Pineville gage and the St. Stephens gage may range from 100 to 400 cfs, with an average over 200 cfs. It is believed that most of the water enters the stream from ground-water storage.

Crawl Creek (fig. 1) originating in the Pleistocene deposits northwest of Russellville loses about 1 cfs within two miles after it enters the swampland. One small-drainage-area creek with a base flow of less than 10 cfs is depleted as it move across the flood plain and enters the Santee River. Several small creeks have their origin in limestone outcrops or sinks along the left side of the swamp, and these may lose flow from place to place to the limestone formation. At least one, with a flow of about 1 cfs, issues from an opening at one side of a sink, moves across the floor of the sink to re-enter a hole on the other side and no flow leaves the sinks on the surface.

Surface-Water Quality

There are insufficient data available on which to base a statement about water quality in the small creeks in the 200 square-mile drainage area. However, available data on the Santee River show that little or no change in the chemical quality of water occurs between the Pineville and St. Stephens gages. Maximum and minimum values of dissolved subtances and physical properties of the water from the Santee River near Pineville for the period October 1951 to November 1974 are listed in table 2.

GROUND-WATER HYDROLOGY

The purpose of this section is to identify the main hydrologic units in the study area and to describe their hydraulic properties. Also, an attempt has been made to identify the hydrologic characteristics and to discuss their effect on yields to wells tapping the main aquifers, as well as to delineate the zones of ground-water recharge and discharge.

Aquifer Systems

Geophysical logs and core logs were used to correlate stratigraphy and construct geological cross-sections identifying permeable zones. Locations of cross-sections are shown in figure 4.

Cross-sections A-A' and B-B' (figs. 5 and 6) are parallel to the canal right-of-way from Lake Moultrie to the Santee River at Lake Mattassee. Cross-sections C-C' and D-D' (figs. 7 and 8) are at right angles to and cross the canal right-of-way near the railroad and the power line easement, respectively.

The principal aquifers found in the St. Stephens area are: (1) a shallow, water-table, sand and clay aquifer, (2) a deeper, artesian limestone aquifer, and (3) a sand and gravel aquifer, which is a remnant of a buried river channel. In this report, these units will be referred to as aquifer 1, aquifer 2, and aquifer 3.

Aquifer 1

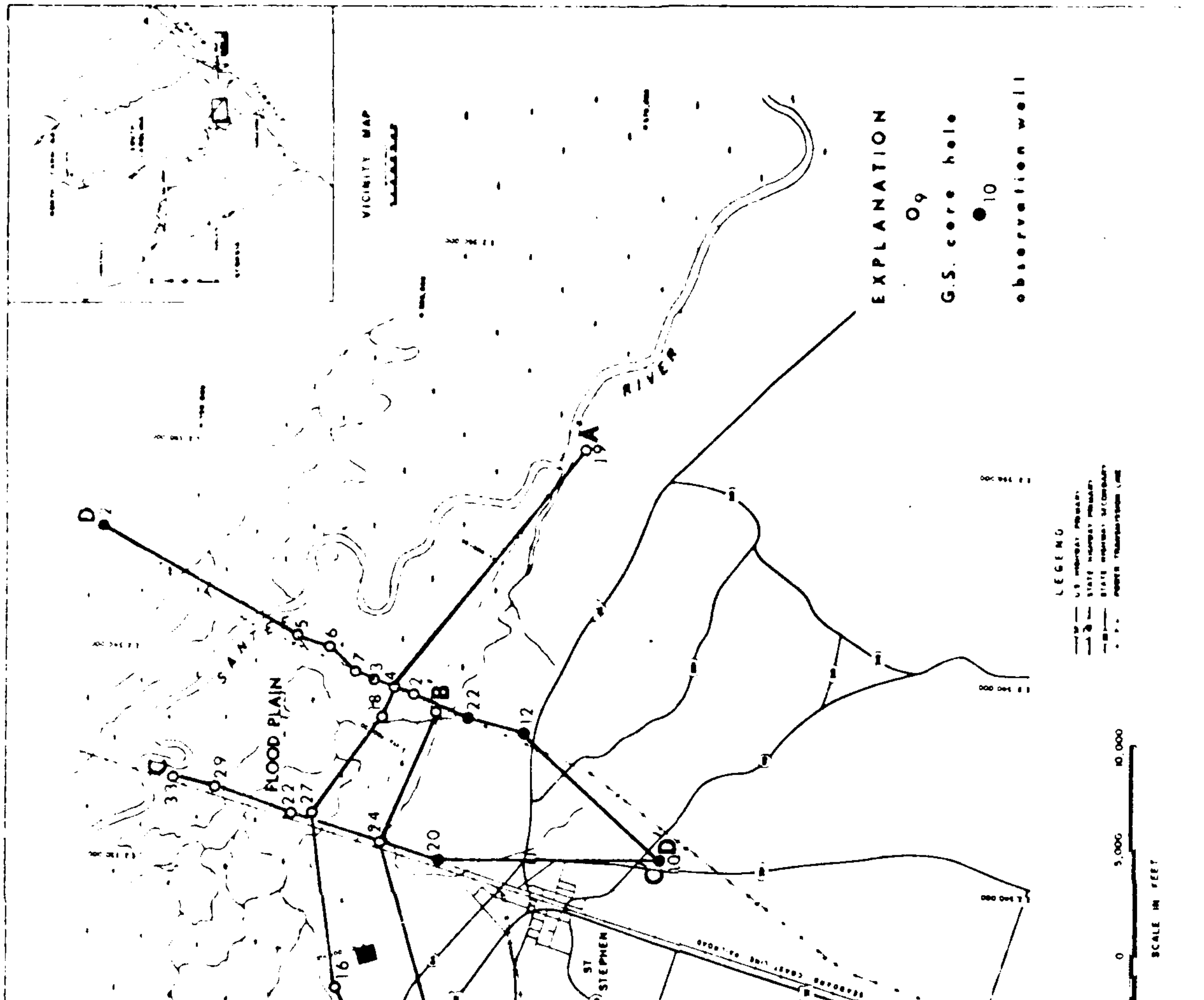
This aquifer comprises the Pleistocene deposits that are found on the plateau area and the adjacent Santee River flood plain. The general configuration of the top surface is shown on the structure contour map (fig. 9). The surface has a regional northwest strike and dips northeast toward the Santee River flood plain. Aquifer 1 ranges in thickness from 10 to 70 feet with the greater thicknesses occurring updip from the Santee River flood plain. It gets thinner in the direction of the flood plain. The sands and clays of aquifer 1 are underlain by a dark gray shale that separates it from aquifer 2.

The intake canal will cut into aquifer 1 from Lake Moultrie to the power house location. The proposed intake canal is a trapezoidal section with a 385 foot wide bottom and levees on both sides. The bottom of the canal is 50 feet above msl from the lake to the power house.

Table 2.--Chemical analysis of water from the Santee River near Pineville.

[Results in milligrams per liter except as indicated. Analyses by U. S. Geological Survey.]

Period of Record	Maximum or Minimum	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved Solids: Calculated	Dissolved Solids: Residue on evaporation at 180°C	Hardness as $CaCO_3$: Calcium Magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific Conductance (micromhos at 25°C)	pH Units	Color units
Oct. 1951	Maximum	12	0.15	6.4	2.4	13	2.5	34	13	12	0.3	1.6	70	74	25	4	111	7.9	60
Nov. 1974	Minimum	1.6	.00	3.5	1.0	4.8	.8	17	3.3	3.0	.0	.1	39	43	15	0	52	6.1	0



EXPLANATION
G.S. core hole
observation well
VICINITY MAP
RIVER
SANTEE
FLOOD PLAIN
PLATEAU
CREEK
LAKE
MOULTRIE
ST STEPHEN
RUSSELLVILLE
LEGEND
SCALE IN FEET

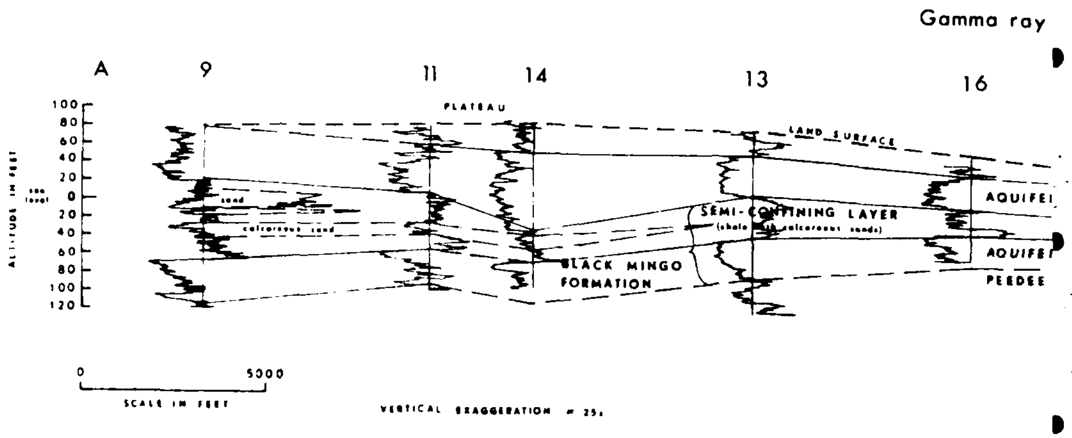


Figure 5. Cross

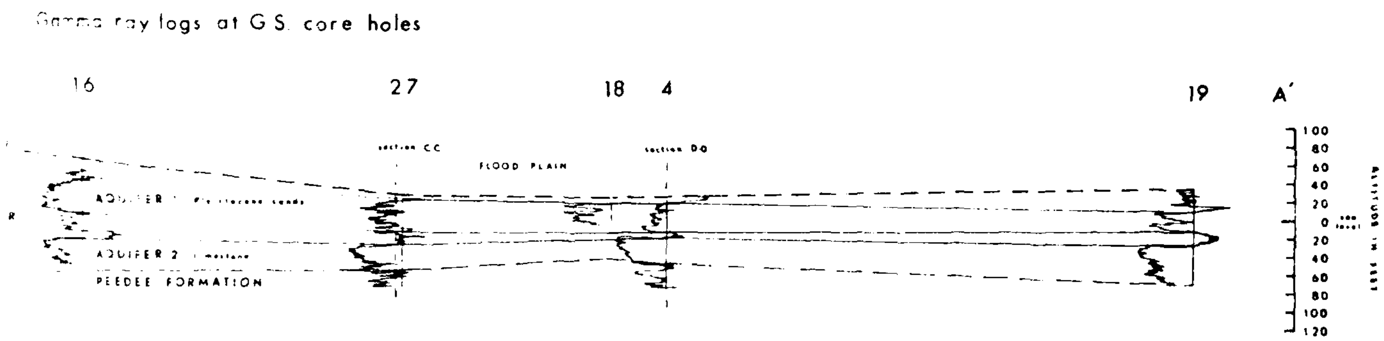


Figure 5. Cross section A-A'

2

Gamma ray logs a

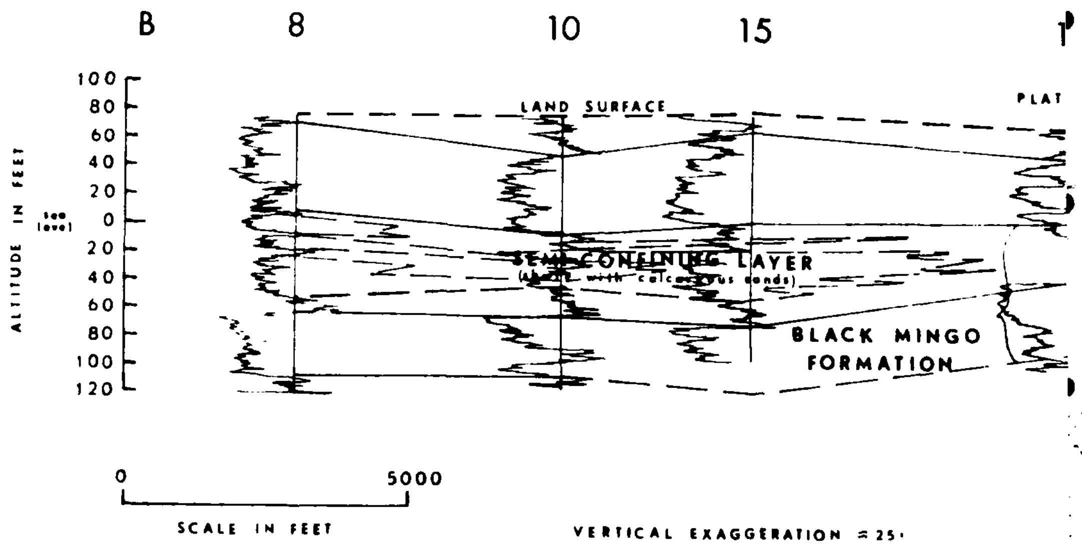


Figure 6.

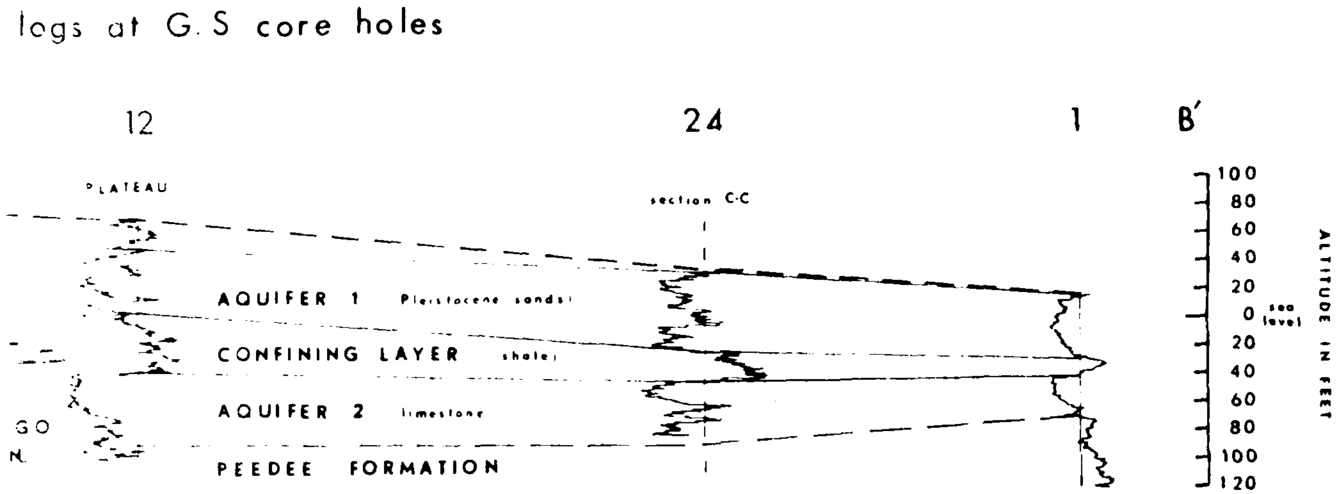


Figure 6. Cross-section B-B′

Gamma ray logs
and obser

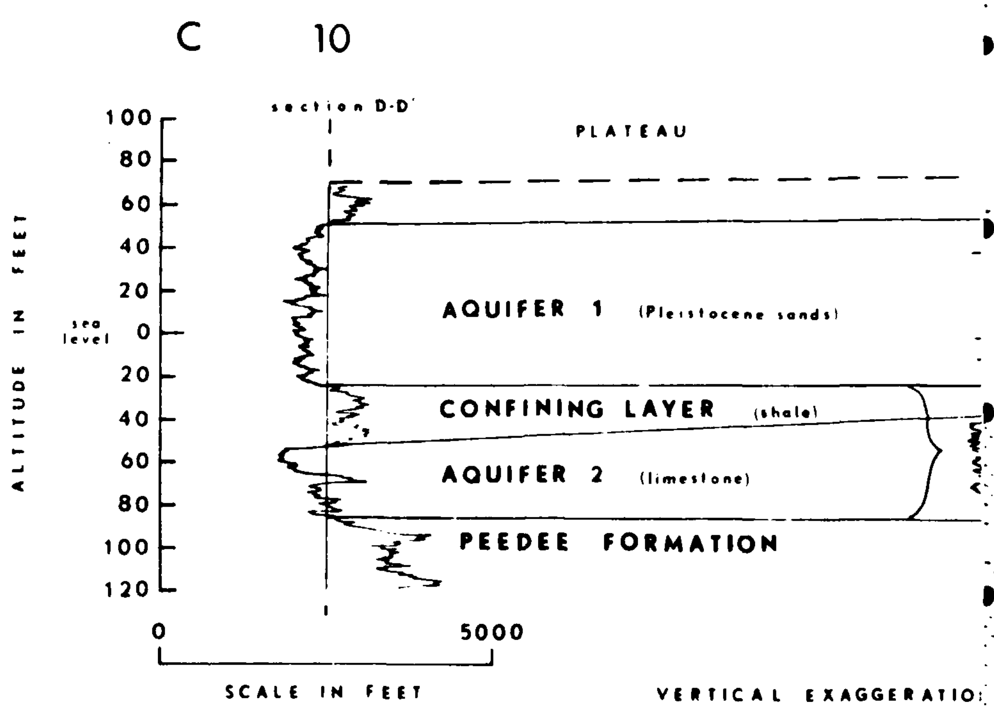
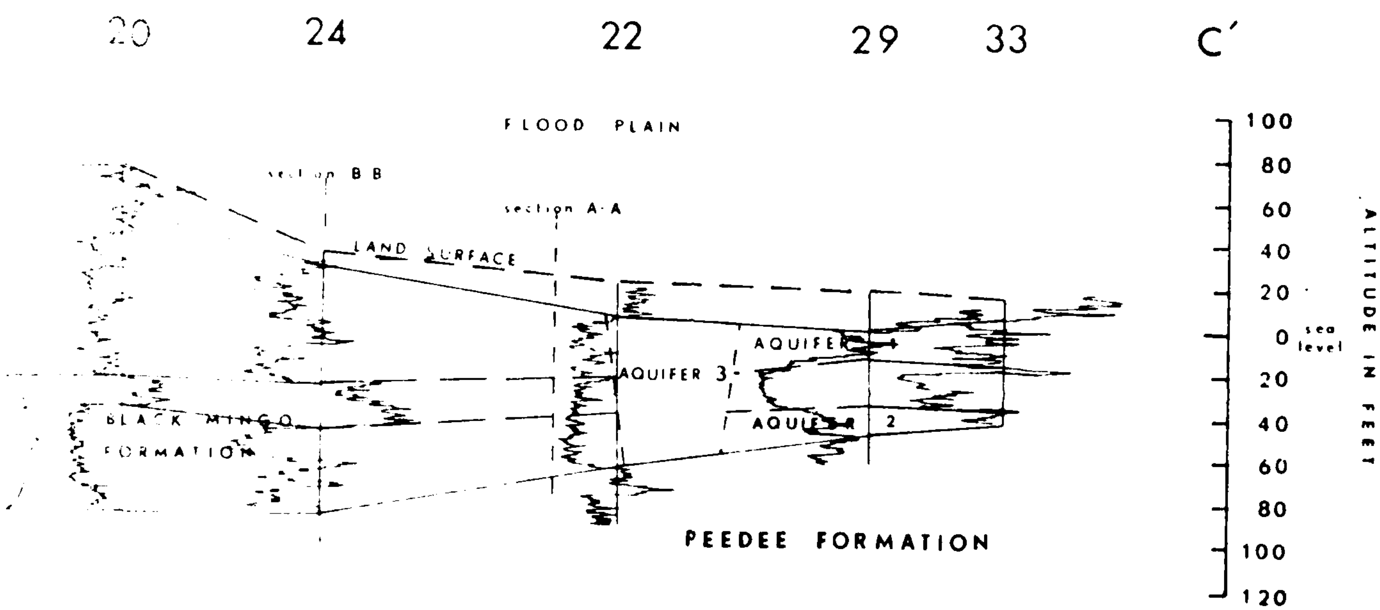


Figure 7. C

5

y logs at G.S. core holes
observation wells

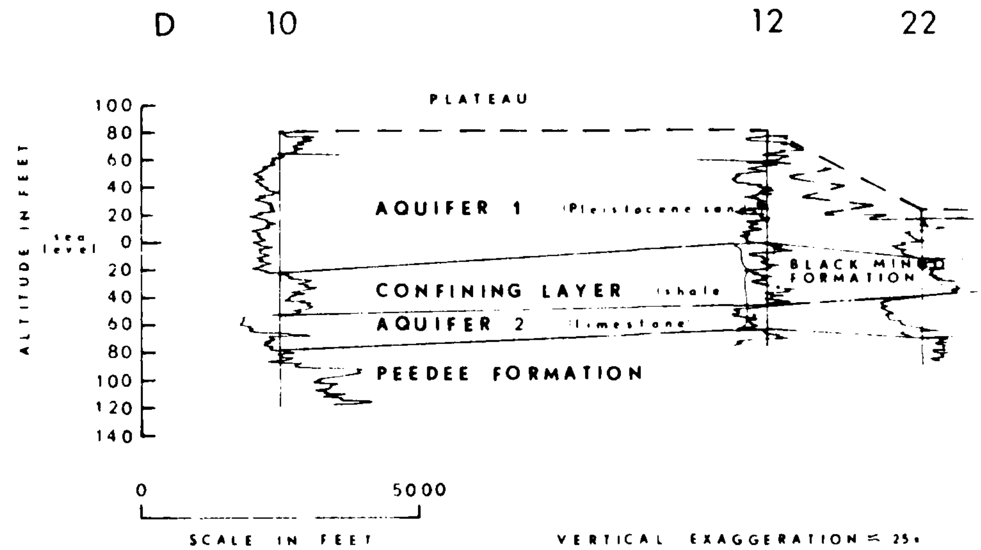


GGERATION

ure 7. Cross section C-C′

6

Gamma ray logs (



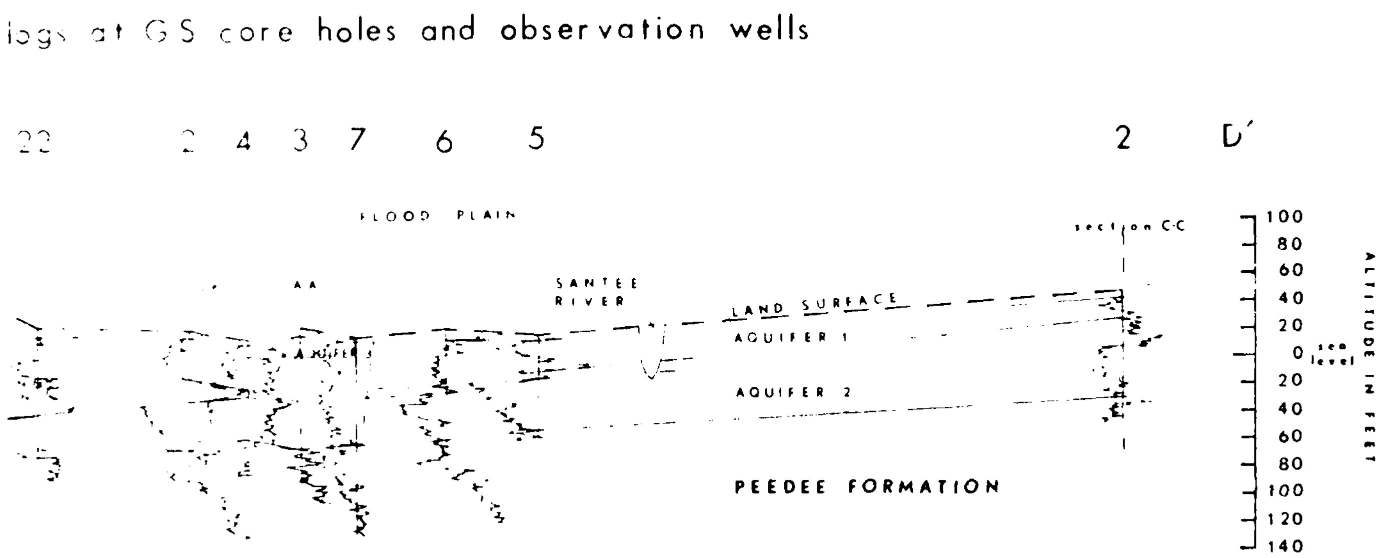


Figure 8 Crosssection D D.

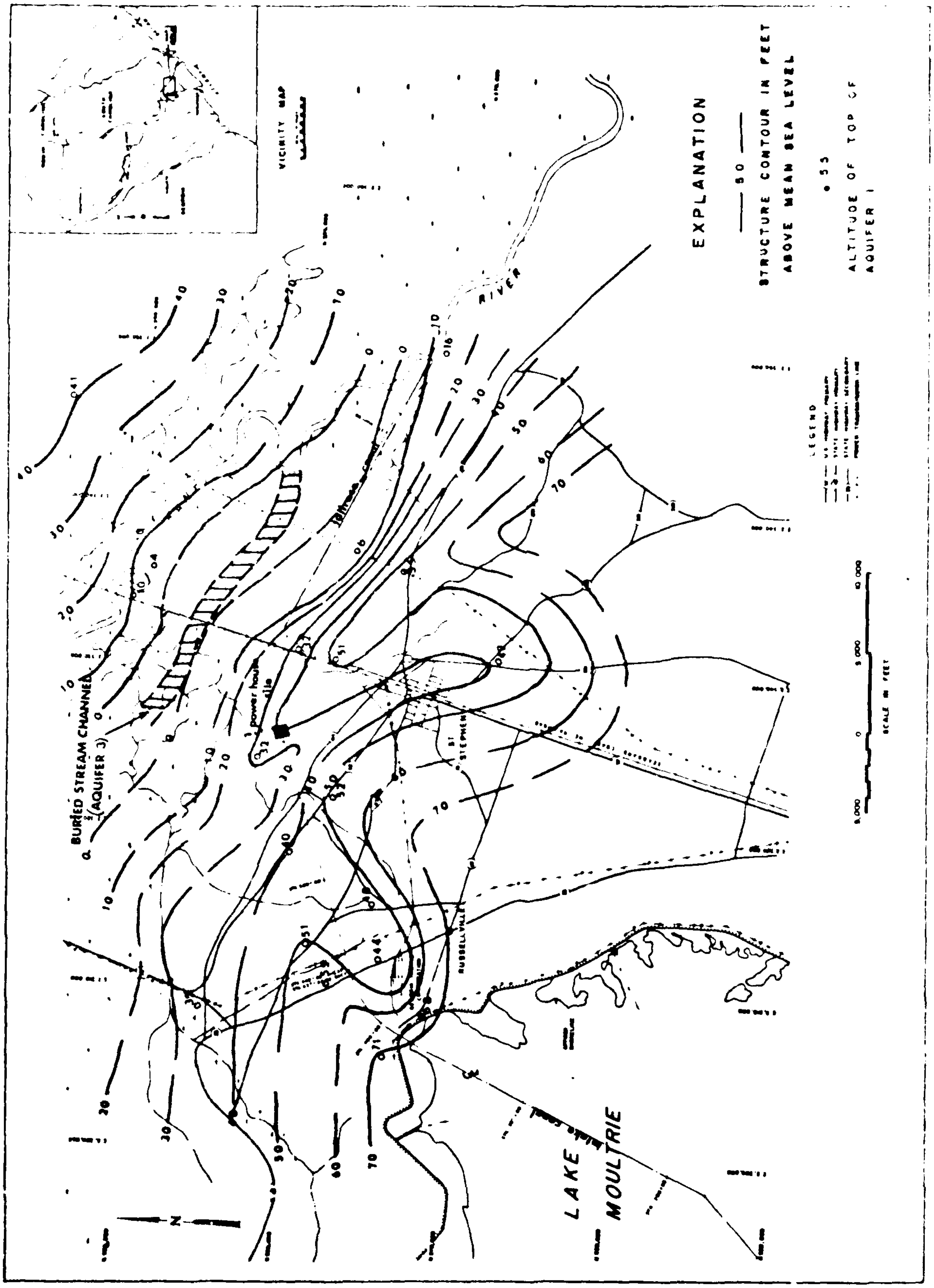
Shallow domestic wells (30 feet or less) tap this aquifer near St. Stephens. Most of these wells are equipped with either pitcher pumps or shallow well jet pumps. The wells are constructed with 2 inch pipe as casing and a 5-10 feet well point (screen) at the bottom. The maximum amount of water each well pumps is about 10 gallons per minute.

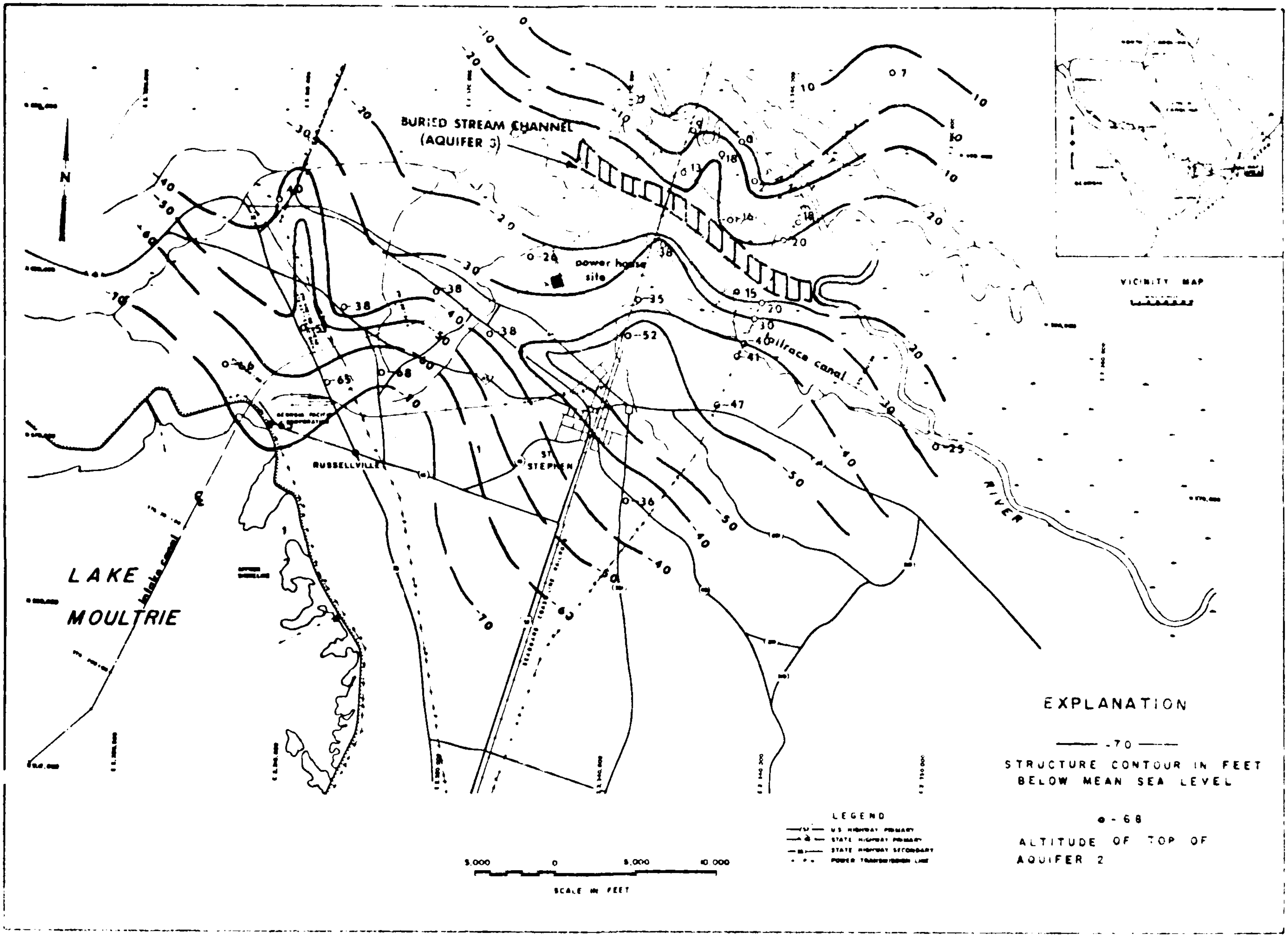
Aquifer 2

Aquifer 2 consists of gray, fossiliferous limestone that is overlain by a dark brittle shale containing thin, gray, sandstone and shell layers. These two lithologic units (shale and limestone) are middle Eocene in age and are commonly called the Black Mingo Formation. The configuration of the top surface of aquifer 2 is shown in figure 10. Aquifer 2 generally ranges in thickness from 18 to more than 58 feet with an average thickness of 37 feet. In the vicinity of the Santee River flood plain, the shale, which is the confining layer for the limestone, has been eroded in some places. In the flood plain, sections of the limestone also have been removed by fluvial erosion.

Neither the intake canal or discharge canal are deep enough to cut into aquifer 2. However, the base of the power house is to be 42 feet below msl near center line station 598 + 50. Excavation to this depth will at least partially intersect the shale layer that confines the limestone at the power house location.

This aquifer is the primary water bearing formation in the St. Stephens area, and the majority of the domestic wells in the area tap it. Wells are drilled to the top of the limestone and a 3-inch


EXPLANATION
50
STRUCTURE CONTOUR IN FEET ABOVE MEAN SEA LEVEL
• 55
ALTITUDE OF TOP OF AQUIFER 1
VICINITY MAP
LEGEND
SCALE IN FEET
BURIED STREAM CHANNEL (AQUIFER 3)
power house site
RIVER
ST STEPHENS
RUSSELLVILLE
LAKE MOULTRIE
N



BURIED STREAM CHANNEL
(AQUIFER 3)
power house site
tailrace canal
RIVER
RUSSELLVILLE
ST. STEPHEN
LAKE
MOULTRIE
Intake canal
N
VICINITY MAP
EXPLANATION
-70
STRUCTURE CONTOUR IN FEET BELOW MEAN SEA LEVEL
o -68
ALTITUDE OF TOP OF AQUIFER 2
LEGEND
5,000 0 5,000 10,000
SCALE IN FEET

pipe is driven into the formation. Open hole drilling inside the 3-inch pipe is completed to 10 or 15 feet into the limestone. The wells are then developed with an air compressor or jet pump. The newer homes near the canal right of way have this type of finished well. Domestic needs of 10 gallons per minute are adequately met from a 3-inch well tapping aquifer 2.

Aquifer 3

This aquifer represents the more permeable lithologic unit of Pleistocene age. It consists of medium-coarse, light-gray-to-green glauconitic sands and gravels. The extent of the aquifer is poorly defined due to a lack of drill holes in areas other than the canal right of way. It is believed, however, that this buried stream channel meanders throughout the Santee River flood plain. Aquifer 3 may serve as a conduit for ground-water discharge or recharge for aquifers 1 and 2. Also, aquifer 3 in places cuts through the Black Mingo shale layer into the limestone and hydraulically connects aquifer 1 and 2.

Although, the extent of this aquifer is not fully known, the tail race canal may cut into these deposits in some places. The cross-sectional dimensions of the tailrace canal are the same as the intake canal, but the base of the tailrace canal will be much lower at 3.5 feet above msl. The general topographic features of the flood plain are at an altitude of 20 feet above msl. The bottom of the canal being at 3.5 feet above msl would allow for the tailrace canal to cut at least 16 feet into the flood plain, thereby, intersecting the shallow deposits of aquifer 3.

[illegible] aquifer 3 because the [illegible] River flood plain is not inhabited.

AQUIFER TESTS

Five aquifer tests, four on aquifer 2 and one on aquifer 3, were made at the conclusion of the drilling program. These tests were [illegible] (2 hours) and drawdown was observed only in the pumping well. A submersible five-horsepower pump was set in each pumped well below the projected pumping water level, and drawdown and recovery water-level data were collected for each pump test. A constant pumping rate of approximately 50 gallons per minute was used for each test.

Aquifer yields were obtained during the development phase of the observation well program. Each well was developed with an air compressor. Air was blown through the drill rods that were lowered in the well. Yields were measured for each well, and an average yield for each aquifer was determined. Approximate average yields of aquifers 1, 2, and 3 were 50, 100, and 150 gallons per minute, respectively.

Of the wells tested, four (8, 10, 12 and 18) (fig. 1) were finished open hole in limestone (aquifer 2) and one well (14) was finished as a gravel-packed well with a slotted screen in aquifer 3. Wells completed in aquifer 2 (table 3) showed a wide range of transmissivities. However, transmissivities in limestone usually reflect only the amount of fracture and solution openings, which can vary considerably with distance. The well completed in aquifer 3 had the highest recorded transmissivity value, which indicated that this aquifer can definitely be an accessible conduit in which large amounts of ground water can move.

[illegible] between transmissivities obtained from specific capacity and time-drawdown curves can be seen in table 3. In general, all the "T" values for both methods of analysis are within agreeable limits. The only exception is well 14, which was completed in aquifer. Partial penetration of the aquifer by the pumping well could be a reason for the discrepancy between time-drawdown and specific-capacity analysis.

Pumping test were also conducted on wells screened in aquifer 1. However drawdown in those wells was excessive. Transmissivity values estimated from specific capacity tests were less than 670 ft²/day ([illegible] gal/day/ft).

The limiting factor affecting the analysis of the pumping-test [illegible] [illegible] of observation wells and the short duration of the test. Therefore, the transmissivities obtained can only be estimates of the amount and rate of water movement in the aquifers. Also, no reliable indication of storage coefficient can be obtained from this type of test.

Power House Aquifer Test

In April 1974, the Corps of Engineers designed and conducted an aquifer test at the power-house site, which is located on the rediversion canal center line at station 598 + 50. The foundation base of the excavation is to be at 42 feet below msl (90 feet below land surface). An average drawdown of about 80 feet will have to be maintained inside the power house excavation until construction is completed. Therefore, insight of the possible extent of dewatering of the aquifers is [illegible]. During the test, aquifers 1 and 2 were pumped separately, and drawdown and recovery of the water levels were measured for each aquifer.

Table 3.--Results of aquifer tests.

Well Number	Aquifer Depth (ft below lsd)	Well Depth (ft below lsd)	Pumping rate (gallons per minute)	Pumping Time (Hours)	Specific Capacity (gallons/ft drawdown)	Transmissivity (a) ft^2/day	Transmissivity (b) ft^2/day	Permeability (ft/day)	Aquifer Thickness (ft)	Aquifer Tested
8	76	113	48	3.7	5	750	870	19	40	2
10	114	140	58	2.8	62	8,500	19,000	170	50	2
12	124	143	50	2.8	3	520	460	29	18	2
14	32	35	49	2.3	42	17,250	9,400	575	30	3
18	56	86	56	1.7	22	3,700	3,350	82	45	2

(a) Computed from time-drawdown curve.
(b) Computed from specific capacity. (C. V. Theis from Bentall, 1963).

$$Ft^2/day = \frac{gallons/day/ft}{7.48}$$ (Coefficient of Transmissibility)

Well screens in the pumping and observation wells in aquifer 1 did not fully penetrate the saturated thickness of the aquifer (fig. 11). The pumping well (46A) had 30 feet of screen, and the observation wells (S1A, S2A, 42A, W1A) only had 5 feet of screen each, placed in the bottom of the well.

Aquifer 1 was pumped at 140 gallons per minute for 2 days with a maximum drawdown of 61.3 feet in the pumping well. The specific capacity of this well was 2.3 gallons per foot of drawdown with a static water level of 48.8 feet above msl. The saturated thickness of the aquifer was defined as between the static water level and the top of the confining shale bed, a distance of 70 feet.

Measured drawdowns in the aquifer 1 test were plotted against $\frac{t}{r^2}$ where t = time in minutes since pumping began, and r = radius in feet from the pumping well. This data was matched against the Theis curve and it was found that data from the wells (S2A and 42A) gave a good match. The transmissivity obtained for aquifer 1 was 870 ft^2/day (6,500 gal/day/ft) and the storage coefficient was 8×10^{-4}. This storage coefficient would indicate an artisan aquifer but, the screen interval for the observation wells is at the base of the aquifer. There are some silt layers and clay layers in the aquifer above this screen interval, which would give an initial storage coefficient value of an artesian system (10^{-4}). However, the long term pumpage and dewatering of this aquifer would indicate a subsequent change of storage to a water table condition. Therefore, an assumed storage value of 1×10^{-1} was used to predict drawdown for long term pumpage. Table 4 shows

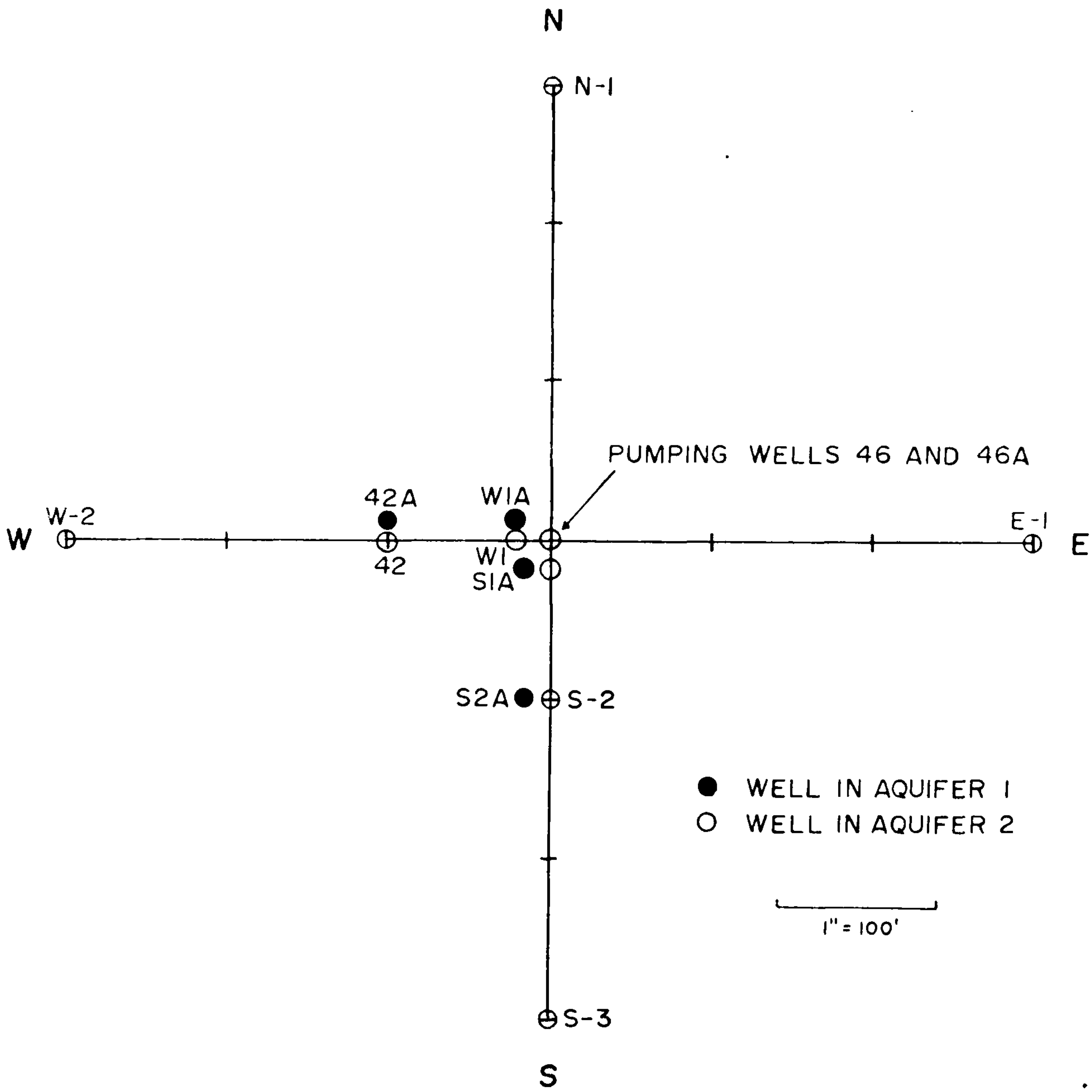


Figure 11.--Diagram of wells used in pump test.

computed drawdowns at specific distances (r) from the pumped well. The arbitrary pumping rate used to predict drawdowns was 300 gallons per minute. Any increase or decrease in this pumping rate would affect the drawdown (s) proportionately. The time (t) for the given drawdowns in table 4 is after 300 days of pumping.

The equation used to predict the drawdowns in the table is:

(Theis) $$s = \frac{114.6Q}{T} W(u); \qquad u = \frac{1.87r^2S}{Tt}$$

s = Drawdown in feet

Q = Pumping rate in gallons/minute

T = Transmissivity. Reported in ft^2/day (gallons/day/ft)

W(u) = Well function of "u"

S = Storage coefficient

t = Time in days

r = Radius (distance in feet from pumped well)

It appears from table 4 that excessive drawdowns will not occur as a result of pumping aquifer 1. However, the assumed storage coefficient of .1 was used to derive "u" in the Theis equation. The drawdowns predicted from transmissivity and storage figures only give an estimate as to the actual drawdowns that will take place in the aquifer during pumping at the power-house site.

Aquifer 2 was pumped at 154 gallons per minute for 2 days with a maximum drawdown of 64.5 feet in the pumped well. The specific capacity was 2.4 gallons per foot of drawdown with a static water level of 38.9 feet above msl. The pumping well and observation wells were finished as open hole wells in the limestone without screen. The casing was ... pvc pipe cemented from the top of limestone to land surface.

Measured drawdowns in aquifer 2 were plotted against $\frac{t}{r^2}$. ... the end of the drawdown test the plotted curves departed from the ... curve. Drawdown curves from wells 42, N-1 and S-3 were matched against a family of type curves by Cooper (in Lohman, 1972). These type curves were established for an artesian aquifer with a "leaky" confining bed. The transmissivity obtained from these curves was 455 ft^2/day (3,400 gal/day/ft) and the storage coefficient was 1×10^{-4}.

The equation used to predict drawdown in an leaky, confined aquifer is $s = \frac{114.6Q}{T} L(u,v)$ where L is the leakance function of u and $v = \frac{r}{2}(\frac{K'}{b'T})^{\frac{1}{2}}$ where K' = hydraulic conductivity of the confining bed, b = thickness of the confining bed, T = transmissivity of the aquifer and r = radius from the pumped well in feet. As v approaches zero, L(u,v) approaches W(u), which is the basic Theis equation for drawdown. The standard type curve for the Theis equation is values of W(u) plotted against $\frac{1}{u}$. Whereas, in the leakance type curves L(u,v) is plotted against $\frac{1}{u}$. The value of v from this equation is proportional to the radius (r) of the cone of depression. The larger the cone, the greater amount of leakage to the aquifer and, thus, the spread of the drawdown cone is slowed.

The constant value of $(\frac{K'}{b'T})^{\frac{1}{2}}$ was 3.35×10^{-4} per foot. Table 4 shows values of computed drawdown for various radii using the leaky aquifer equation. Drawdowns were determined assuming a 300 gallons per minute pumping rate for 300 days.

Table 4.--Computed drawdowns from aquifer test data.

Aquifer I

Q Pumping rate in gallons/minute	t Time in days	r Radius in ft	s drawdown in ft
$T = 870\ ft^2/day$ (6500 gpd/ft) $S = 1 \times 10^{-1}$			
300	300	1000	9.9
300	300	3000	1.5
300	300	5000	.1
300	300	9000	0

Aquifer II

Q Pumping rate in gallons/minute	t Time in days	r Radius in ft	s drawdown in ft (Theis only)	s (Recharge effect)	s (Leakage effect)
$T = 455\ ft^2/day$ (3400 gpd/ft) $S = 1 \times 10^{-4}$					
300	300	1000	81	64	28
300	300	3000	59	41	8.1
300	300	5000	49	32	[illegible]
300	300	9000	37	19	1

* $Ft^2/day = \frac{gallons/day/ft}{7.48}$ (Coefficient of Transmissibility)

Certain reservations have to be taken into account when using leakance equations. It is assumed that the capture of water from the aquifer by discharging wells is, in fact, due to leakage from the confining bed. It is also assumed that the ratio K'/b' is arealy constant. The leakance equation should only be used when there is reliable aquifer test data as well as a good understanding of the local geology.

Therefore, as a result of pumping both aquifers 1 and 2, drawdowns will probably be in a range between the maximum and minimum drawdown numbers. Actual water level declines that will take place in the aquifer cannot be accurately predicted due to the combined effects of variable leakage and line sources of recharge.

The effect of the pumping at the power-house site (aquifer 1 and 2) cannot be fully evaluated without an accurate well inventory. There will be some water level decline in aquifer 1 and 2 but what effect this will have on local water uses is not known unless a well inventory is taken which consists of the well location, depth of well and pump setting, type of pump and water-level measurements. The depth of well, construction, and location would tell how many people are using aquifers 1 and 2. Information on pump depth, type of pump and water levels would give an indication as to what effect drawdown from the power house dewatering would have on that particular water user. The information gathered in a complete well inventory would help determine any deterimental effects to local water users resulting from pumping to dewater the power house construction site, which could then be the basis for contingency plans to alleviate any potential problems.

POTENTIOMETRIC SURFACES AND DIRECTION OF GROUND-WATER MOVEMENT

Ground-water movement in the St. Stephens area is generally from the vicinity of Lake Moultrie toward the Santee River and at right angles to the contour lines.

Potentiometric contours for aquifers 1 and 2 (figs. 12 and 13) show that the highest water levels occur near Lake Moultrie and gradually decline toward the Santee River. Water levels about 75 feet above msl near Lake Moultrie and are generally less than 20 feet above msl in the flood plain. Water level contours of aquifers 1 and 2 are similar and an increase in the water-level gradient occurs near the flood plain where the topography changes. Potentiometric contours in aquifer 1 usually follow the topography. The water surface in the upper sands generally lies within a few feet of land surface, and the distance between points of recharge and points of discharge (nearby streams) is relatively short. The similarity in contour maps for aquifers 1 and 2 can probably be attributed to a common recharge and discharge area. However, the variation in thickness of the confining layer and the close agreement of the potentiometric surfaces would suggest some degree of hydraulic connection between aquifers 1 and 2. Water levels of aquifers 1 and 2 and the channel fill (aquifer 3) appear to merge in the flood plain and the stage in the river possibly affects water level fluctuations in all of them.

Minimum water levels were observed in all observation wells in the study area in November 1973. Water-level declines in the flood plain can possibly be attributed to either low water stages in the Santee River, ground-water discharge to the river, or evapotran-

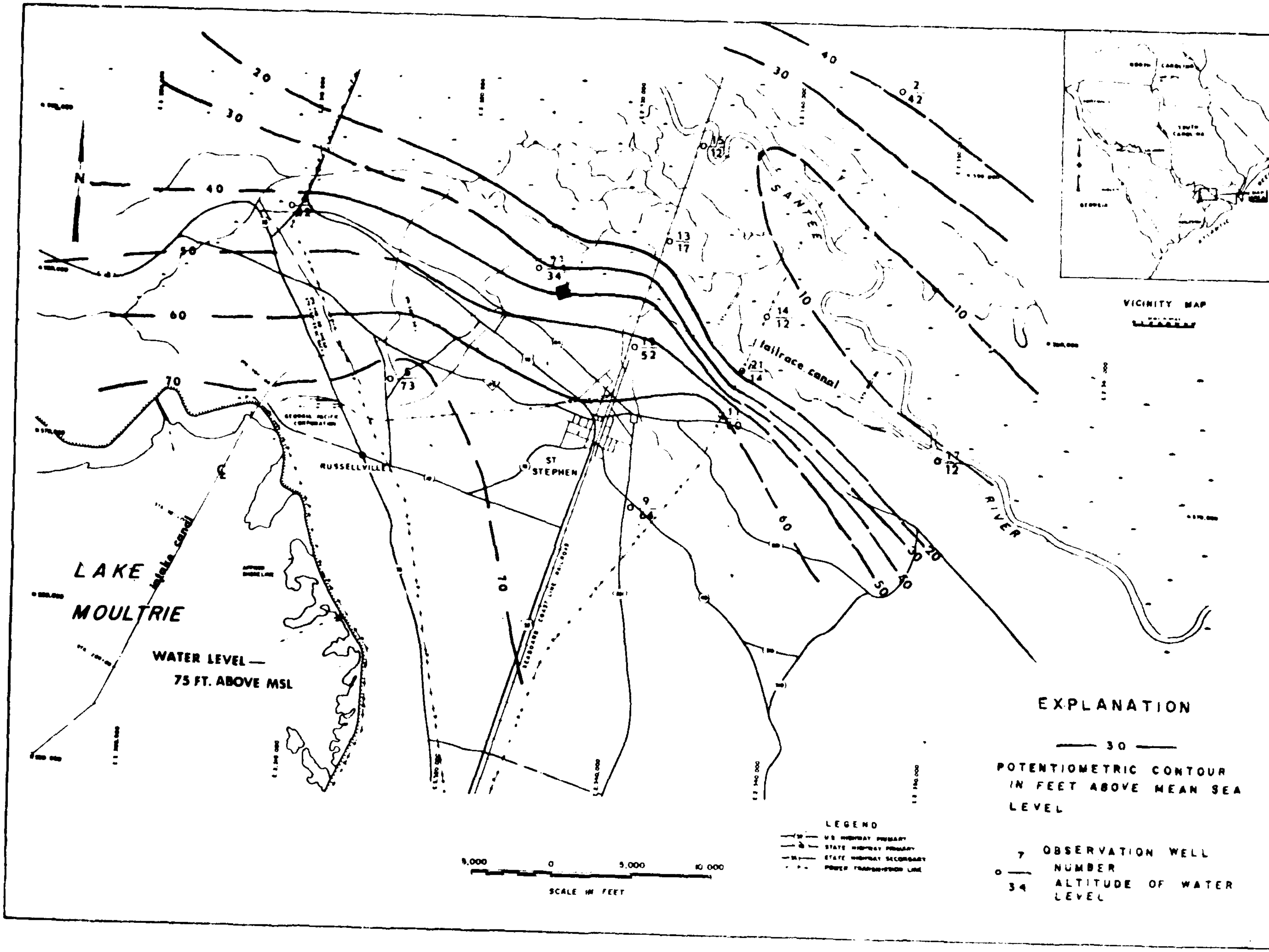
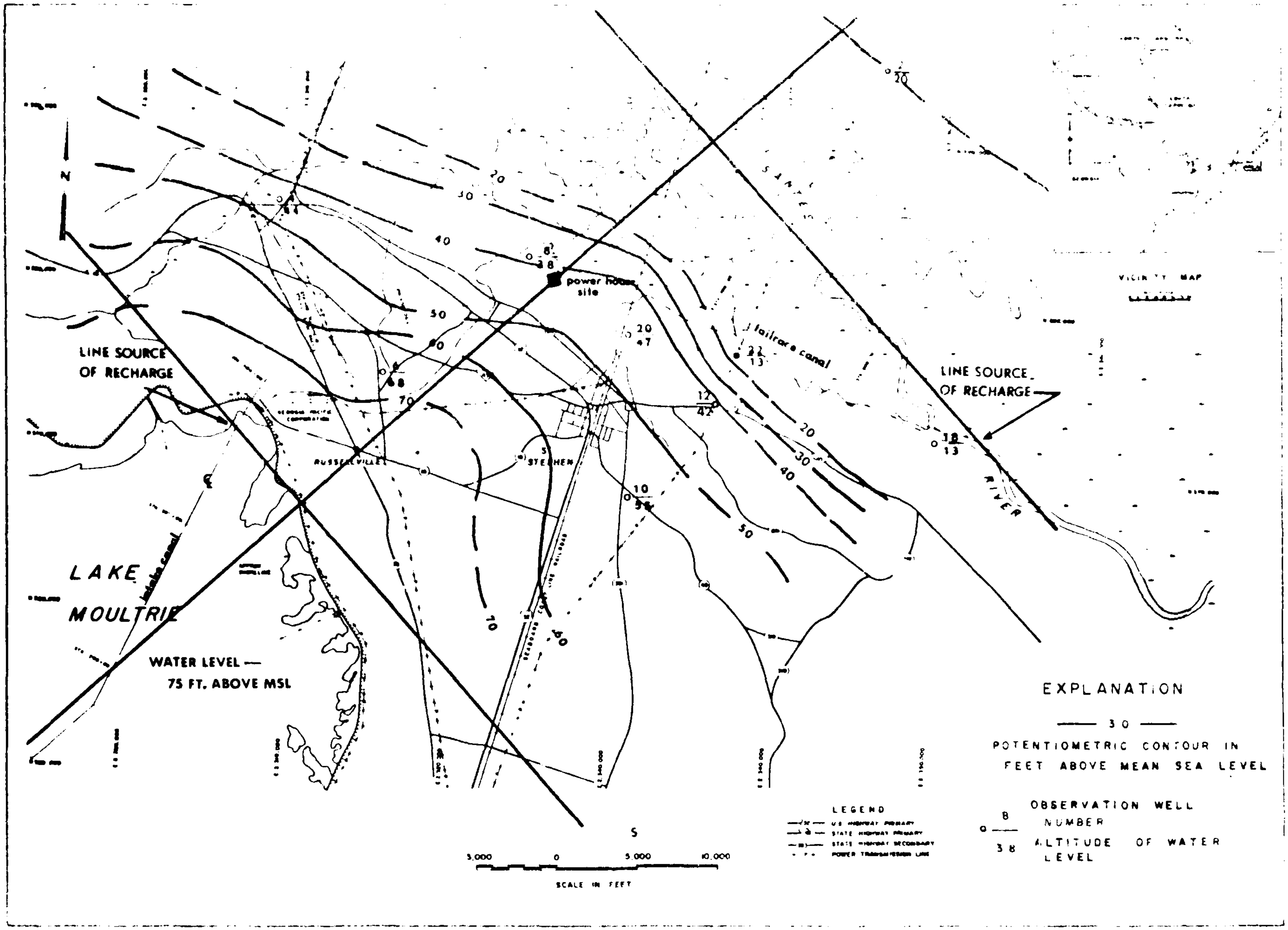
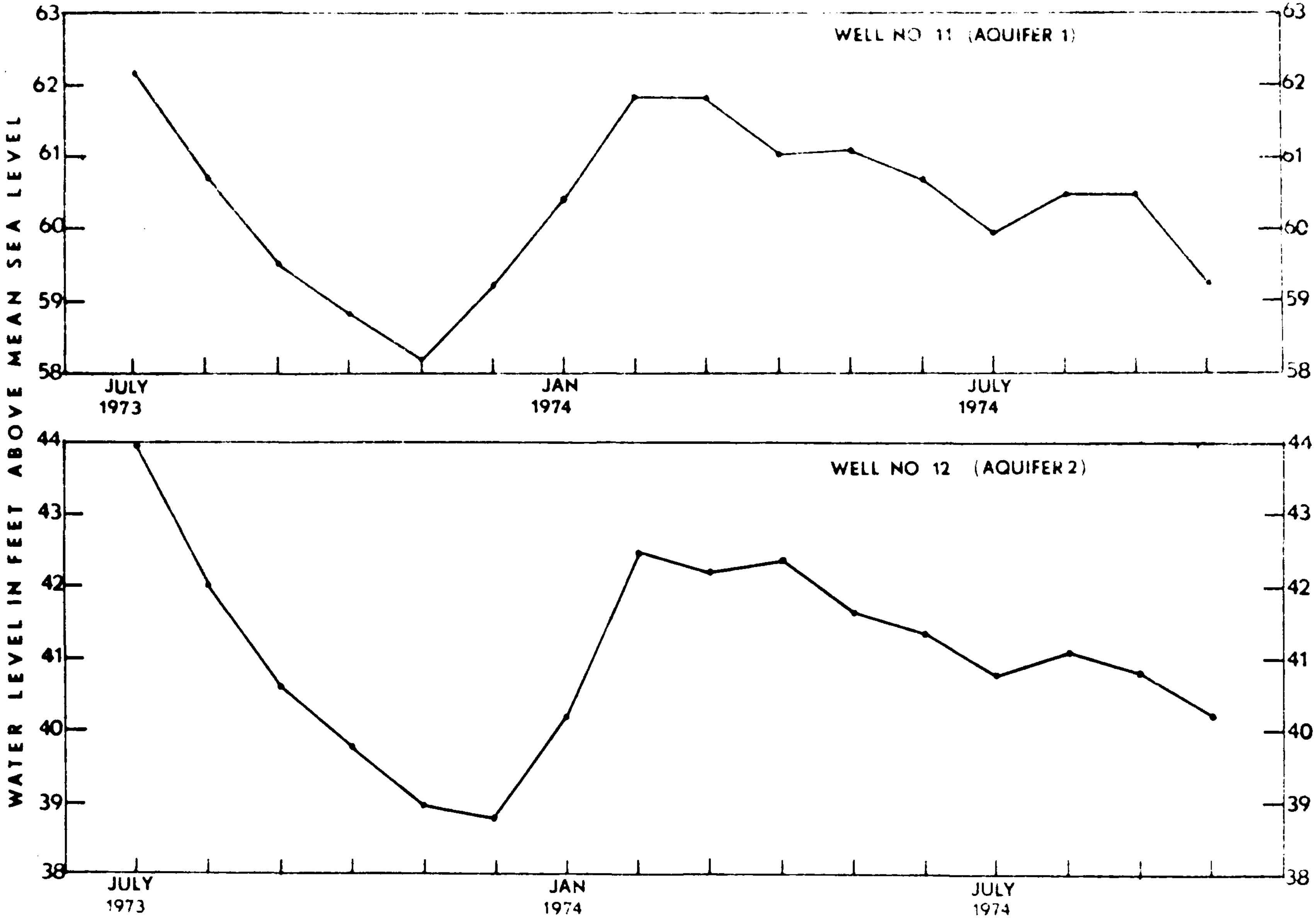


Figure 17.--Potentiometric surface of

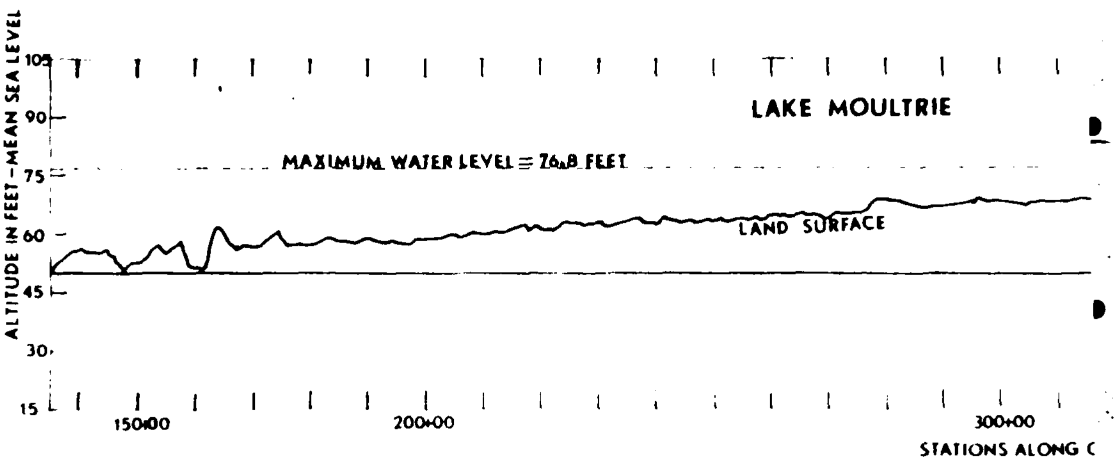

N
S
LINE SOURCE
OF RECHARGE
LINE SOURCE
OF RECHARGE
power house site
tailrace canal
SANTEE RIVER
RUSSELLVILLE
ST. STEPHEN
LAKE MOULTRIE
WATER LEVEL — 75 FT. ABOVE MSL
VICINITY MAP
20
30
40
50
60
70
EXPLANATION
30
POTENTIOMETRIC CONTOUR IN FEET ABOVE MEAN SEA LEVEL
OBSERVATION WELL
8 NUMBER
38 ALTITUDE OF WATER LEVEL
LEGEND
U.S. HIGHWAY PRIMARY
STATE HIGHWAY PRIMARY
STATE HIGHWAY SECONDARY
POWER TRANSMISSION LINE
5,000
0
5,000
10,000
SCALE IN FEET

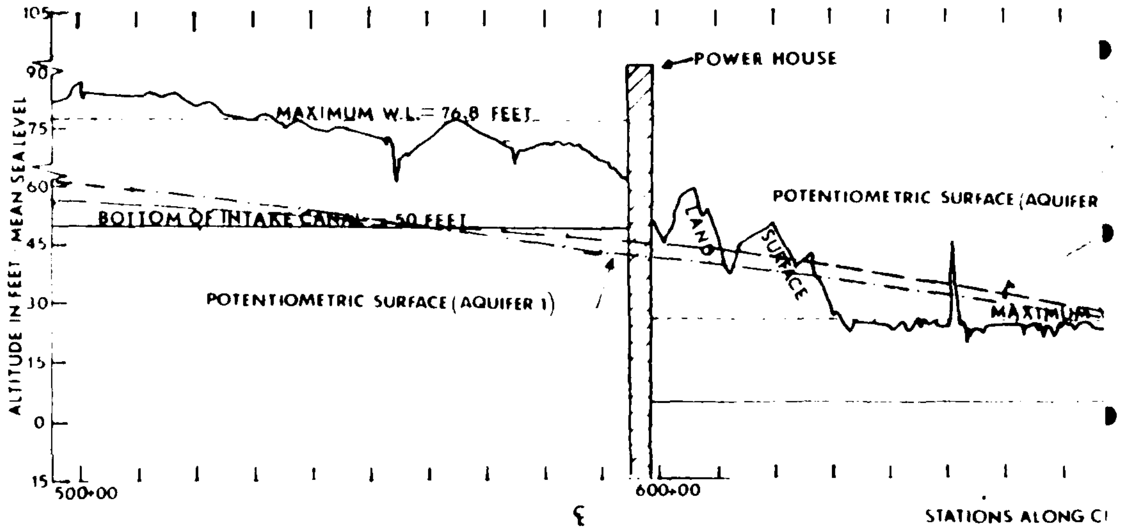

WELL NO 11 (AQUIFER 1)
WELL NO 12 (AQUIFER 2)
WATER LEVEL IN FEET ABOVE MEAN SEA LEVEL
63
62
61
60
59
58
44
43
42
41
40
39
38
JULY 1973
JAN 1974
JULY 1974

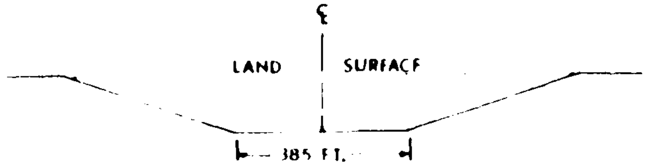
the Santee River, ground water discharge to the river, or evapotranspiration. On the plateau declining water levels are probably due to head pumpage, lack of precipitation, ground-water discharge to the river, or high evapotranspiration rates.

Figure 14 shows hydrographs for wells 11 and 12. The location of these wells is shown in figure 1. These hydrographs are representative of water level fluctuations for aquifers 1 and 2. Well 11 represents water levels in aquifer 1 and well 12 represents those in aquifer 2. The difference in water levels between the two hydrographs is approximately 20 feet, indicating no apparent hydraulic connection between the aquifers at this well site. The initial high water level in 1973 is due to inundation of the flood plain by the Santee River. The ground water gradient in the flood plain reversed causing higher water levels in wells adjacent to the flood plain. As shown in the graph, ground water levels declined as the high water in the flood plain receded.

The potentiometric surface of aquifer 1 and 2 is about 75 feet above msl near Lake Moultrie and gradually declines to about 40 feet near the power-house site. Figure 15 shows the potentiometric surface of aquifers 1 and 2 through the center-line profile of the canal. Maximum water level of the proposed intake canal is 76.8 feet above msl (fig. 15). Therefore, the intake canal may recharge the aquifers as a result of head differences between the canal and the aquifers. The confining layer between aquifer 1 and 2 is not uniform in thickness and downward leakage may occur from the intake canal through the shallow sands to the limestone.







CANAL SECTION

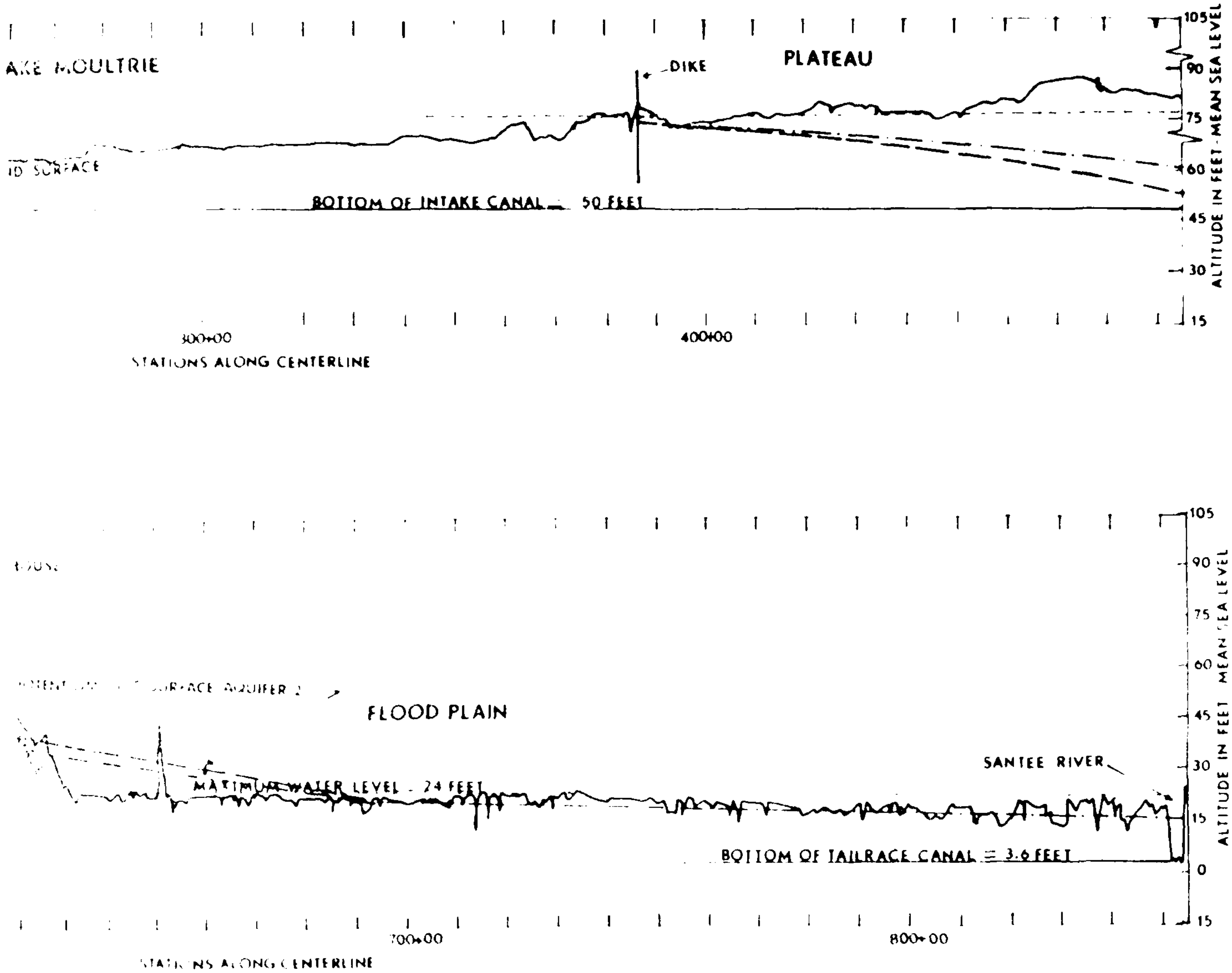


Figure 15. Diagram showing canal center line profile.

10

Measured water levels in aquifers 1 and 2 fluctuate ... the flood plain. Most of the tailrace canal will traverse the flood plain to the Santee River. The maximum water level of the tailrace canal is 24 feet above msl. The 24 foot level will occur at a maximum release of 24,500 cubic feet per second. The ... discharge will be 1?,000 cubic feet per second with approximately ... water level. Some recharge to the aquifer could occur at ... stage in the canal. However, less head in the tailrace canal ... cause a decrease in the recharge effect and an stabilization of water levels between the aquifers and canal.

GROUND-WATER CHEMICAL QUALITY

Ground water, under normal conditions, is usually more highly mineralized than surface water. The chemical quality of ground water is largely controlled by the soluble mineral constituents of the aquifer material or water-bearing unit in which the water slowly moves for a long period of time. The concentrations of dissolved constituents in ground water generally increase with greater depth and greater distance from the source of recharge (Back, 1963).

Detailed chemical analyses of water samples from selected wells were obtained from the Survey's laboratory. Samples of water from wells 6, 10, 12 and 14 (table 5) were collected for analysis at the conclusion of the development phase of well construction. Measurements of temperature, pH, and conductance were obtained in the field.

Most of the analyses show a reasonably high bicarbonate (HCO_3) content, which is characteristic of limestone waters in the Coastal

Plain. The analysis from well 14, located in the old buried river channel, is the only sample obtained from wells in the flood plain due to its inundation during drilling. This analysis shows a [illegible] change in both pH, bicarbonate, and iron content and indicate a mixing between water in the flood plain deposits and the limestone.

Water Temperature

Water temperatures were measured as the wells were drilled. The average temperature of the water for wells finished in limestone was 19° Celsius while the water from a well finished in flood plain deposits was somewhat lower, 16.5°C. Mean annual air temperature is approximately 19°C, and most of the limestone wells reflect average temperatures that would indicate the waters were confined for a reasonable length of time. The water temperature of 16.5°C from wells finished in the flood plain deposits indicate possible mixing of ground water and cooler surface water from inundation of the flood plain by the Santee River.

Table 5.--Chemical analyses of water from observation wells.

Well No.	Aquifer	Date of sample collection	Silica (SiO_2)	Iron (Fe) (Total)	Aluminum	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Alkalinity (As $CaCO_3$)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (Sum)	Residue solids	Hardness as $CaCO_3$	Specific conductance a/	pH b/
7	1	5/1/73	35	.560	.040	33	1.9	7.7	1.5	118	97	4.0	6.0	0.2	0.0	150	148	90	[illegible]	7.2
9	1	5/15/73	22	.010	.010	30	1.3	3.6	1.3	94	77	0.8	6.0	0.5	0.8	110	115	[illegible]	[illegible]	7.2
11	1	5/3/73	21	.050	.080	32	1.7	3.8	2.5	103	84	1.2	5.0	0.2	1.0	[illegible]	131	87	[illegible]	7.7
21	1	6/7/73	37	.030	.060	50	2.8	14	4.0	178	146	5.2	12.0	0.3	1.6	[illegible]	214	140	[illegible]	7.4
4	2	5/16/73	30	.020	.070	24	7.8	11	8.0	133	109	4.0	5.0	0.3	0.0	[illegible]	185	92	229	7.7
8	2	4/30/73	30	.070	.100	40	1.3	3.9	1.7	125	103	2.8	5.0	0.2	0.0	[illegible]	147	100	270	7.3
10	2	5/25/73	27	.700	.040	53	1.7	4.6	2.0	170	139	1.6	8.0	0.2	0.0	180	180	140	285	7.5
12	2	5/3/73	28	.010	.010	66	3.0	9.8	4.2	230	189	0.4	10.0	0.5	0.0	230	240	180	380	7.4
20	2	4/16/73	25	-	-	56	2.4	7.2	2.6	192	157	0.8	6.0	0.1	0.0	[illegible]	197	150	320	7.7
22	2	6/6/73	35	.020	.050	50	4.0	20	9.0	222	182	0.8	6.0	0.3	0.1	[illegible]	234	92	[illegible]	7.7
14	3	6/4/73	25	2.2	.020	20	2.8	9.4	2.3	78	64	2.1	12.0	0.2	[illegible]	110	114	[illegible]	[illegible]	6.7

[illegible] Specific conductance and pH [illegible]

SUMMARY

The drilling phase of the study consisted of 33 core holes located along and at right angles to the canal right-of-way. The purposes of the core holes were to delineate the subsurface geology and to locate possible sites for the observation-well network. As a result, 20 observation wells were drilled to monitor water levels before, during, and after construction of the canal and power house.

Three aquifers in the study area were delineated: aquifer 1, a shallow (40-60 feet) sand which supplies limited amounts of water to shallow wells; aquifer 2, a confined limestone (90-120 feet) which is the most widely used aquifer in the vicinity of the canal right-of-way; and aquifer 3, a sand and gravel remnant of a buried stream channel found in the flood plain.

An aquifer test was conducted at the power-house site. Aquifer 1 and 2 were pumped separately. The transmissivity of aquifer 1 was 870 square feet per day (6,500 gallons/day/foot) and the storage coefficient was 1×10^{-1}. The transmissivity of aquifer 2 was 455 square feet per day (4,000 gallons/day/foot) and its storage coefficient was 1×10^{-4}.

During construction of the power-house foundation, heavy pumping of aquifers 1 and 2 will occur. Drawdowns of 80 feet or more would need to be maintained within the excavation.

It appears that excessive drawdowns would not occur as a result of pumping aquifer 1. However, the assumed storage coefficient of .1 was used to derive "u" in the Theis equation. The drawdowns predicted from transmissivity and storage figures only give an estimate as to the actual drawdowns that would take place in the aquifer during pumping at the power house site.

Maximum drawdowns (aquifer 2) were computed without the recharge or leakance effect and minimum drawdowns were computed on the basis of "leakage". Considering only the effect of line source recharge, the drawdowns would occur between the maximum and minimum numbers. Data shows that there would be very little drawdown in aquifer 2 if the "leakage" assumptions are correct and a large amount of drawdown if no recharge or leakage occurs.

Potentiometric contours of aquifers 1 and 2 show that the highest water levels occur near Lake Moultrie and gradually decline toward the Santee River. Potentiometric contours in aquifer 1 usually follow the topography. The similarity in contour maps for aquifers 1 and 2 can probably be attributed to a common recharge and discharge area for both aquifers. Water levels of all three aquifers appear to merge in the flood plain and the stage in the river possibly affects water level fluctuations in all of them.

The potentiometric surface of aquifers 1 and 2 is about 75 feet above msl near Lake Moultrie and gradually declines to about 40 feet near the power-house site. The maximum water level of the proposed intake canal is 76.8 feet above msl. Therefore, the intake canal may recharge the aquifers as a result of a head difference between the canal and the aquifers.

The maximum water level of the tailrace canal is 24 feet above [illegible] recharge to the aquifers could occur at maximum stage in the canal. However, less head in the tailrace canal would cause a decrease in the recharge effect and an equalization of water levels between the aquifer and canal.

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